AFRL-SN-HS-TM-2003-003

LEFT-HANDED ELECTRODYNAMICS AND MICROWAVE MESOSTRUCTURES

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In-House Report: February 2001 – November 2001

APPROVED FOR PUBLIC RELEASE

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
21 May 2002

3. REPORT TYPE AND DATES COVERED
15 Feb.. 2001 - 5 Nov. 2001 Final

4. TITLE AND SUBTITLE
Left-Handed Electrodynamics and Microwave MesoStructures

5. FUNDING NUMBERS
PE 61102F
PR 2305
TA GN
WU 01

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/SNHA
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Hanscom, AFB
MA 01731-2909
POC: Dr. John S. Derov

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
We have started to investigate the fundamental electromagnetic properties of left-handed mesostructures in order to establish a basic understanding of their electromagnetic properties. Simulations have been performed on left-handed structures using Agilent's high frequency structure simulator. The structures were fabricated and measured in X-band waveguide. They were found to have a passband near 10 GHz. This wavequide technique is less complex than previously published chamber techniques.

14. SUBJECT TERMS
meta-materials, left-anded materials, negative index materials, NIM

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASIFIED	UNCLASSIED	UL

Final Report
Left-Handed Electrodynamics and Microwave Mesostructures

Most ordinary materials exhibit both positive dielectric permittivity, ε, and positive magnetic permeability, μ. In 1967, V. G. Veselago[1] theorized that if materials existed with negative ε and negative μ, they would 'reverse' many common electromagnetic properties. For instance, the index of refraction could be negative, meaning that a refracted ray is bent toward the same side of the normal axis as the incident ray. A convex lens, which is normally convergent, would be divergent in a negative index material and likewise, a concave lens would be convergent. Another interesting consequence occurs between two media where $\varepsilon_1 = -\varepsilon_2$ and $\mu_1 = -\mu_2$. A ray incident at the interface of the two is totally refracted without any loss to reflection.

The first practical demonstration of a "left-handed" ($-\varepsilon$, $-\mu$) medium did not occur until May, 2000 by D. R. Smith et al[2]. Their mesostructure is combined from copper split ring resonators and posts on ordinary 0.25mm thick fiberglass G10 printed circuit board in a two dimensional periodic lattice. The operating frequency was near 10GHz. The unit cell is less than one-tenth that wavelength and therefore below the diffraction limit. Their measurements were performed in a custom-built guided wave scattering chamber.

We investigated the possibility of performing meaningful initial measurements of such material in standard X-band (8-12GHz) waveguide. First it was necessary to adapt the post and ring structure to the substrate material we had available, which was 60mils thick. The structures were modeled using Agilent HFSS (High Frequency Structure Simulator). Because of the intensive memory requirements for the simulator, it was necessary to simplify the model to achieve practical processing times. Therefore we studied the rings and posts separately within waveguide boundary conditions.

The split rings by themselves have positive ε at all frequencies and negative μ only in a narrow band near their resonance. The frequency of resonance is determined by the capacitive coupling between the inner and outer split rings. Microwave transmission through the split rings is very low at resonance. The metal posts by themselves have positive μ at all frequencies and negative μ in a range below the so-called plasma frequency. This frequency is determined by the width, thickness and spacing of the posts. Transmission through the posts is very low below the plasma frequency. It was necessary to ensure first that the frequency regions of $-\varepsilon$ and $-\mu$ would overlap. This produces a negative index material with a pass band in the overlap of what are separately low transmission regions. It was also necessary to ensure the frequencies of interest were within the band of the waveguide.

The geometrical parameters were adjusted to achieve this. The final version of the split rings had outer dimensions of a 106 mil square. The width of each square ring strip was 10 mils and the gap between the inner and outer rings was 12 mils. The split in each ring was 20 mils across. The resonance predicted by HFSS occurred at 10.5

GHz. The final version of the posts was 20 mils wide. They were simulated as a group of nine, due to the computing limitations mentioned. The predicted transmission was below –20 dB across X-band, indicating the plasma frequency was above the band. Since transmission decreases as the number of posts increases, it was expected the value would be even lower for the actual number used in the measurement.

The structures were fabricated on 60 mil G10 circuit board by milling. The basic unit cell which was repeated consisted of three rings, stacked to the height of the waveguide (400 mils), and one post on the back of the substrate aligned with the split in the rings. Four unit cells were used across the width of the waveguide (900 mils). Nine unit cells were spaced down the length of the waveguide filling 2 inches total. First the rings were end-milled out of the copper coating on one side of the G10. Then with careful alignment to the front, the posts were milled on the backside copper. Between adjacent unit cells, a 60 mil slot was milled all the way thru the substrate so the pieces could be assembled into an interlocking two-dimensional lattice or crate. Pieces with only rings and only posts were also milled so they could be measured separately to verify the simulations.

Measurements of the three crates were done using a HP 8510 Network Analyzer. The split rings alone resonated at 10.74 GHz (Figure 1), very near the predicted value. The 2 inch long crate of posts showed less than 60 dB transmission over most of the band (Figure 2). This is very near the noise floor of the instrument and displays improvement over the prediction due to the increased number of posts. The measurement of the "left-handed" crate with front to back rings and posts is shown in Figure 3. The transmission shows two pass bands of –40dB near 10 and 11 GHz, frequencies where the posts did not transmit. It was discovered by further experimentation that the performance could be improved (Figure 4). This crate was formed by using boards with posts alone across the waveguide and rings alone down the length of the waveguide. The transmission improves to –25 dB in a single band.

[1] V. G. Veselago, "The Electrodynamics of Substances With Simultaneously Negative Values of ε and μ ", Soviet Physics, Vol. 10, No. 4, Jan. 1968, pp509-514.

[2] D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, " Composite Medium with Simultaneously Negative Permeability and Permittivity", Physical Review Letters, Vol. 84, No. 18, May 2000, pp 4184-4187.

Figure 1. Rings alone

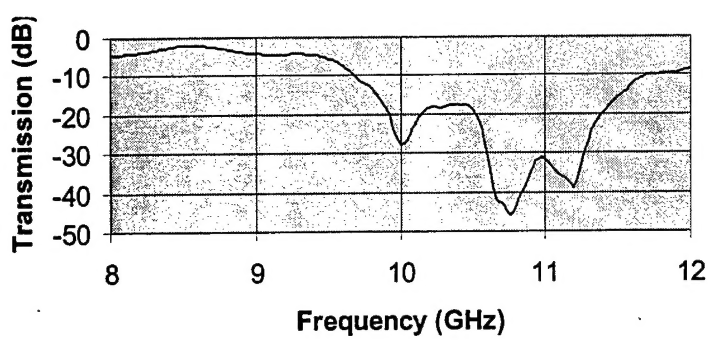

Figure 2. Posts alone

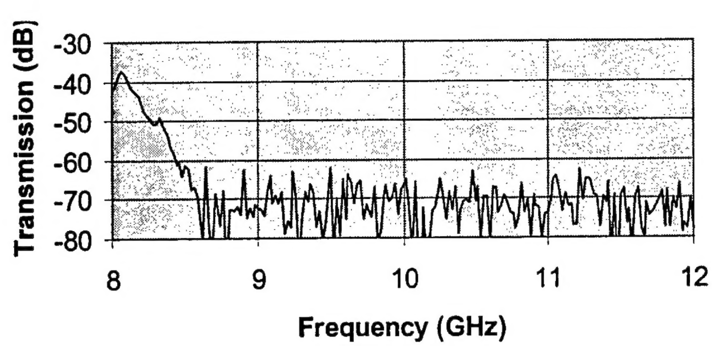

Figure 3. LHM crate

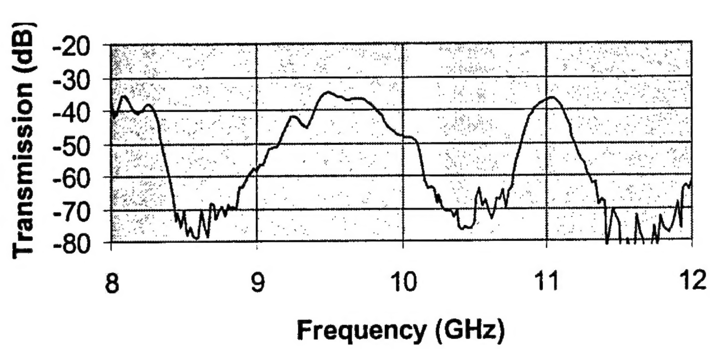

Figure 4. Improved LHM